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PAT HUTCHINSON

BOTTOM FEATURES OF THE BEAUFORT SEA

JIM SHEARER

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PHYSICAL ENVIRONMENT OF THE BEAUFORT SEA

A background discussion of the physical properties and features of the Beaufort Sea will be given here. The basis for presenting this information at this time is that it is felt that much of the basis for the petroleum industry's activity in the Mackenzie Delta area, is the potential of the sedimentary basin underlying the continental shelf of the Beaufort Sea.

This panel will deal mainly with the physical features and processes encountered in the Beaufort Sea.

They will consist of:

- (1) The near surface geology of the bottom of the sea and its features specifically related to the Beaufort Sea including offshore pingos, sea bottom permafrost and sea bottom scouring (Shearer J.) entitled "Bottom features of the Beaufort Sea"
- (2) The coastal zone where the transition between the land areas and Beaufort Sea take place (Lewis C.P.) entitled "Physical aspects of the Beaufort Sea Coast" and
- (3) The climatic and oceanographic properties of the Beaufort Sea, specifically those related to the harsh weather conditions; i.e. the nature of ice movements and timing of breakup is to be discussed by Allen Milne in his presentation of "Preliminary environmental assessment of offshore drilling for oil in the Beaufort Sea".

All three presentations will deal with these topics in the context of offshore oil exploration and possible future production.

BOTTOM FEATURES OF THE BEAUFORT SEA

The Beaufort Sea is commonly considered that area of the Arctic ocean which borders the land masses from Point Barrow, Alaska to the Arctic Islands in Canada and runs the great circle route directly from Point Barrow to Prince Patrick Island. (Figure 1)

It is the continental Shelf of the Beaufort Sea off the Mackenzie Delta with water depths running to 200 m. that we are concerned with here. (Figure 2).

In the southern Beaufort Sea off the Mackenzie Delta the seasonal variation in temperature and sediment load is most severe because of the contrast in Mackenzie River runoff from winter to summer. The river runoff is much higher in the summer containing a much larger sediment load than in the winter-time. ERTS satellite photographs of the western Canadian Arctic continental shelf from Herschel Island to just east of Kugmallit Bay show a NE trend in the Mackenzie river runoff. This easterly moving longshore current is predominant throughout the year and is somewhat more pronounced in the summertime when the Mackenzie outflow is higher. The Coriolis force associated with this high volume outflow is thought to be the major influence in determining current direction. Because of the law of conservation of momentum any major movement northwards on the earth's surface will veer towards the east in the northern hemisphere.

The presence of this Mackenzie water modifies the ambient marine environment with a warm fresh water layer of between 15 and 20 metres thick, extending sometimes far offshore to the shelf edge. Where it touches the bottom in water depths less than 15-20 m., there exists a mean annual temperature on the

bottom much warmer (slightly above zero) than at greater depths where the temperatures were found to be below 0 degree C. (between -1°C. and -1.5°C.) even in the summertime. At depths less than 2 metres, shorefast ice touches the bottom for 8 or 9 months of the year allowing conductive heat transfer to the bottom, thus causing temperatures to be even less than -1.5°C.

The presence of continental glaciers over the North American continent some 15,000 to 30,000 years ago tied up much of the ocean's waters, lowering the world wide sea level some 100 metres. A major event on the continental shelves bordering the Beaufort Sea during this last Wisconsin glaciation, then, was the exposure (down to present depths of about 100 m.) of the shelf to low mean annual air temperatures such as exist on the Tuktoyaktuk peninsula at the present time. The result of such conditions existing for 10,000 or 20,000 years was the formation of a permafrost layer some 200 to 300 metres thick. Upon transgression (sea level rise) of the sea and submergence of these previously exposed areas, the regime of permafrost growth was altered. Presumably as the sea transgressed over any given point a positive temperature existed for a few thousand years when water depths were between -2m. and -20m. This being the case, degradation and melting of the top of any existing permafrost would have taken place during this time. With a mean annual temperature just above zero, it is thought that melting of the top down to some 50 to 70 m. below the sea bottom took place during that few thousand years. As the sea level continued to rise, and depths greater than 20 metres occurred over any given point, the advent of below zero temperatures (-0.5°C. to -1.5°C.) would have reversed the trend and caused renewed downward freezing. This refreezing from the surface downwards implies the existence of frozen ground on the surface. Nevertheless on many seismic records the top of the permafrost is still apparently at -50 m. or so below the sea bottom (Figure 3). Two main reasons for this apparent disagreement are (a) that there



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is a sedimentary change at this level with the overlying very fine sediments, because of their small pore spaces, not freezing solid at the temperatures and (b) that the material is sandy with large pore spaces that became filled with salt water during the couple of thousand years when they were unfrozen, (at water depths of -2 metres to -20 metres).

In some nearshore areas frozen ground may be found very close to the surface because shoreline retreat is very high and the frozen ground has not had enough time to respond to the average positive temperatures in the shallow water zones.

With a change in mean annual temperature on the surface, from -10°C . to -1.5°C . the new base of the permafrost layer would be much closer to the surface. The reason for this, is that the new equilibrium depth for the base of the permafrost layer (i.e. where heat loss to the surface from the cold is equal to heat gain from the centre of the earth) is much shallower than when temperatures were much colder (-10°C .).

Offshore permafrost then (Figure 4) is a relict phenomena (formed 20,000 years ago) with the top being preserved by the presently existing conditions (mean annual bottom water temperature of -1.5°C .).

Not all areas offshore became frozen when exposed above sea level during the last glacial period. As on the Tuktoyaktuk peninsula now, large lakes where the ice did not freeze to the bottom in winter have a perennial layer of unfrozen fresh water underneath. Likewise, underneath deep river channels (greater than six feet deep) the soils may be unfrozen. With the onset of the sea level rise and replacement of this unfrozen fresh water (in these previously protected deep lakes) by salt water at negative temperatures, a unique features developed. The formation of subsea pingos (2125 discovered to date) is another

significant morphological feature occurring after submergence. (See figure 5).

Pingos in the subsea mode are formed by the same mechanism as those formed in the subaerial environment, except that they have formed in response to a negative mean annual bottom water temperature of -1.5°C . compared to a low mean annual air temperature of -10°C .

Upon examination of the detailed bathymetric maps these features are found to exist over much of the continental shelf, but are absent over a broad area north west of the Mackenzie River delta (Figure 2). The trough observed on the chart has been called the "Mackenzie canyon" and is thought to have been the locale of a large ice tongue during the last glaciation. This explains why no offshore permafrost is found here; i.e. because the area was not exposed to low mean annual air temperatures.

Mackenzie Bay and the Beaufort Sea receive sediment mainly from Mackenzie River runoff and from erosion of the shoreline by wave action and melting of the ground ice in summer time. Thicknesses of sediment are very high in Mackenzie Bay with a significant decrease, from over 300 feet to 30 feet or less, as one moves further east. Generally, much of the sediment observed (figure 6) to the east was deposited in river channels at the time of lower sea level and does not represent areas of recent deposition of Mackenzie River sediment.

It has been found in both the Alaskan and Canadian Arctic continental shelves: that large ice Islands and pressure ridges (Figure 7 & 8) when frozen into the polar pack, may encounter the bottom (Figure 9) forming trenches or scours, kilometres in length and up to 10 metres in relief. The water depths to which scouring is significant is defined by the draught of ice fragments

floating in the pack ice. The thickest observed pressure ridge, to date, was found from a Polaris submarine to be 153 feet below mean sea level. All the ice islands (Figure 7 is an example) found in the Canada basin section of the Arctic Ocean and western side of the archipelago come from the Ward Hunt ice shelf on Ellesmere Island. These ice Islands have been found to have a maximum draft of up to about 120 feet.

Scouring is a cumulative process such that with time enough scours may exist in any one given area, so that when further scouring occurs an older scour is overrun. This phenomena is called the saturation level and is expressed generally as the largest average number of scours observed per kilometre, (around 15 to 20) (Figure 10). The time taken to reach the saturation level is unknown, but is presumed to be much less in shallower water. Most scouring is thought to take place in water depths of 10 to 30 metres, and with time, a gradual accumulation of scours at greater depths will occur and the saturation level will be reached. Beyond 150 feet, it is assumed that not enough time yet has passed for this number to be reached. The paucity in very shallow water (<25 feet) is thought to be due to a combination of a higher rate of sediment in-filling and lack of scouring because of the shorefast ice.

Figure 11 is a side scan record taken in about 20m. of water, where the level of scouring is very close to saturation, but where a fresh scour can be distinguished from older ones. Although no concrete knowledge of the age of this scour is known its relative age is quite self evident; the reason for such contrast, being due to the high rate of sedimentation in the area (Mackenzie Bay). In Figure 12, all the scours seem very fresh although they are presumed to be quite old because the record is located east of the Mackenzie Canyon some 40 miles north of Atkinson Point where the rate of sediment in-filling is very small.

Repetitive side scan surveys over the same areas (ranging from shallow to deep areas) should after a number of years give an idea of the time frame involved in the additions of scours.

Figure 13 and 14 show the areal distribution of scour frequency and maximum scour depth for much of the offshore area of the Beaufort Sea. These figures were constructed from original Canadian Geological survey data by the Arctic Petroleum Operators Association. Figure 13 shows that saturation scouring has occurred to depths of about 40 to 50 metres (≈ 150 feet) although as pointed out earlier I feel the rate of scouring decreases significantly beyond the 30 metre line. Figure 14 demonstrates that no matter what age, most scours have a relief (dig into the bottom) of less than 10 feet (Figure 15). Nevertheless a scour with a relief of 10 metres has been found on the west side of Mackenzie Bay.

Much of the area of the Beaufort Sea favorable for oil exploration and production is in areas of frequent scouring, offshore permafrost and offshore pingos.

I feel that in terms of exploration drilling, the variability of climate and irregularity of moving ice present more of a problem than the scouring, pingos and/or offshore permafrost. The permafrost and associated surface hydrate problems that are encountered in exploration drilling on land will likewise exist offshore and may become a significant problem here (offshore). These surface weather conditions might provide the one added complicating factor that could push the operation beyond the critical point.

The well head is planned to be buried in a silo, below the level of maximum scouring for the given area, so that when completed it will be out of danger.

Depending upon the method of production of oil and/or gas, a number of problems may exist.

If one assumes that initial processing of either must take place on shore, then the presence of flow lines is the first requisite. As mentioned previously, in evidence presented titled "A possible future scenario for petroleum development in the Beaufort Sea" these flow lines must be buried so as to avoid contact with floating ice. Depending upon where the first discoveries are made, and subsequent detailed work on the shortest flow line (and perhaps natural channel) to shore it may only be necessary to bury some parts of the line to 10 feet or so, with other sections (in depths of water greater than 180 feet) just layed on the surface.

The potential burial leads to the next problem of offshore permafrost and it's potential destruction from a hot flow line.

The flowlines must be kept hot so that "slug flow" and higher viscosity does not form in the gas and oil respectively.

Again, depending upon where the discoveries are made, and after detailed surveying of the most likely route to shore, it may be found that very little frozen ground exists along the route chosen. If in fact it was found that burial must take place in a zone where frozen ground exists, it would be necessary to insulate the hot wired "flow line" from this by having a refrigeration coil on the outside of this line.

If frozen ground can be avoided by an offshore hot flowline, what actual effect will this hot line have on unfrozen sediments. Likewise, if it is possible to process subsea in deeper water (> 180 feet) what will be the effect of a chilled gas line on these unfrozen yet, below zero temperature, sediments.

An alternative to shipping oil to the south by pipeline down the Mackenzie is to use tankers and/or submarines. This is thought to be quite difficult because of the severe winters in this area. Nevertheless if this mode of transportation is chosen it would necessitate more detailed bathymetric surveys to locate all the subsea pingos that exist offshore. The Manhattan on its voyage through the Beaufort Sea missed, by one nautical mile, totally by accident a subsea pingo on which it would have run aground. This was found to be the case after two years of somewhat intensive soundering surveys. But even so, some of the line spacing for this survey was wide enough to miss completely some of these bottom features. At this point one does not know how many have been missed, nor in fact if any have.

The basis for the information presented here was the research carried out under the auspices of the Geological Survey of Canada.

FIGURE 1

This shows the whole of the North American Arctic.

FIGURE 2

This Figure shows the edge of the continental shelf to exist 60 to 100 miles offshore north of from Garry Island to Cape Dalhousie. On the west side of Mackenzie Bay, a rather steep side/canyon, on the west side at least, exists very close to shore.

FIGURE 3

This is a low energy airgun seismic record taken on the west side of Kugmallit Bay. The hard reflector observed is thought to be a return signal from frozen ground. This is interpreted as such because the velocity contrast between the sediment and the frozen ground is very high and would be expected to show up as seen.

FIGURE 4

This is a Figure showing the rough distribution of offshore permafrost in the Beaufort Sea *calculated using the front ends of the* seismic records from Gulf Oil's offshore seismic exploration program. As explained later the Mackenzie Bay area does not seem to have any frozen ground.

FIGURE 5

This is again a lower energy airgun seismic reflection record showing a submarine pingo. Note that the vertical and horizontal scales here are not the same, so that in fact the pingo is flatter than seen here. Also note the subbottom horizons running underneath the pingo. This is important, because it demonstrates that this feature is not a mud diaper or plug from far below, otherwise this underlying layer would not

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be flat. This is the major physical feature, along with the depression or moat on either side, indicating this is a pingo formed in an old lake basin after being covered with salt water.

FIGURE 6

This is a Figure of mud thickness measured from high frequency echo sounding records. Outside of the Mackenzie Bay area the mud thickness is quite thin. Note that the areas of offshore pingos and offshore permafrost are outside the old river channels.

FIGURE 7

This is a Figure of an ice Island aground in 40 feet of water on the west side of Mackenzie Bay. Note the horizontal lamination of the ice. The Island is roughly 50 m. across and 6 m. high above the water line.

Figure 8

This is of a multiyear pressure ridge thought to be aground in 80 feet of water some 40 miles north of Tuktoyaktuk. It is about 70 m. across and 10 m. above the water line. Note the irregular chunks of ice from which it is composed. Both these pieces of ice have about $\frac{1}{4}$ of their total height above the water line.

FIGURE 9

This shows a large chunk of muddy bottom frozen onto a piece of ice. I think that this soil was from grounding ice, although the possibility that it came from the shoreline exists.

FIGURE 10

This is a histogram of the numbers of scours observed at given depths.

FIGURE 11

The ship was moving from left to right in centered white area. The image is very similar to a radar or airphotograph only it is taken using sound waves as the energy source and taken under water.

FIGURE 13

Note the indentation and lower scour frequency in the older channels running out from the East Channel and other ones from near Atkinson Point.

FIGURE 15

This an echo sounding record over an area in Mackenzie Bay showing scouring in different depths of water.

JIM SHEARER

BORN: August, 1940

CITIZENSHIP: Canadian

EDUCATION: B.Sc., 1963, Geology and Mathematics, Carleton University, Ottawa, Ontario.

M.Sc., 1973, Marine Geology, Memorial University, St. John's, Newfoundland.

WORK EXPERIENCE:

1959-1963 Undergraduate Student; hard rock mineral exploration during summers in Central Newfoundland

1964-1965 Geological Survey of Canada; seismic refraction studies; bottom sampling and coring from C.S.S. Hudson in Hudson Bay.

1965-1969 Graduate Student; marine geology and sedimentology

1969-1970 Bedford Institute of Oceanography, Department of Energy, Mines and Resources; Marine seismic survey work in the northern Gulf of St. Lawrence Grand Banks of Newfoundland and the Labrador sea.

1970-1973 Geological Survey of Canada; carried out a research program in the western Canadian Arctic collecting baseline information for the bottom of the continental shelf of the Beaufort sea. This consisted of Mackenzie delta sedimentation, offshore permafrost, subsea pingos and seabed scouring by moving ice.

1973-1974 Consultant with Huntex (70) Ltd. working on marine pipeline routes for the Polar Gas project.

1974-1975 Geological Survey of Canada; physical environmental studies for the Beaufort sea project.

1975- Independent geologist with COPE and CARC assisting in preparation of evidence for the Berger inquiry.

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